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Conservation of Land and Water Resources of Nebraska

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University of Nebraska-Lincoln

CONSERVATION OF LAND AND WATER RESOURCES OF NEBRASKA

By G. E. CONDRA

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As defined by law, the Conservation and Survey Division of the University includes the following state departments and surveys: Soil, Geological, Water, Biological, Industrial, Conservation, and Information Service. Its major purpose is to study and describe the state's resources and industries for use in development. Reports of the Division are published in three series, i.e., Nebraska Soil Survey, Nebraska Geological Survey, and the Conservation Department.

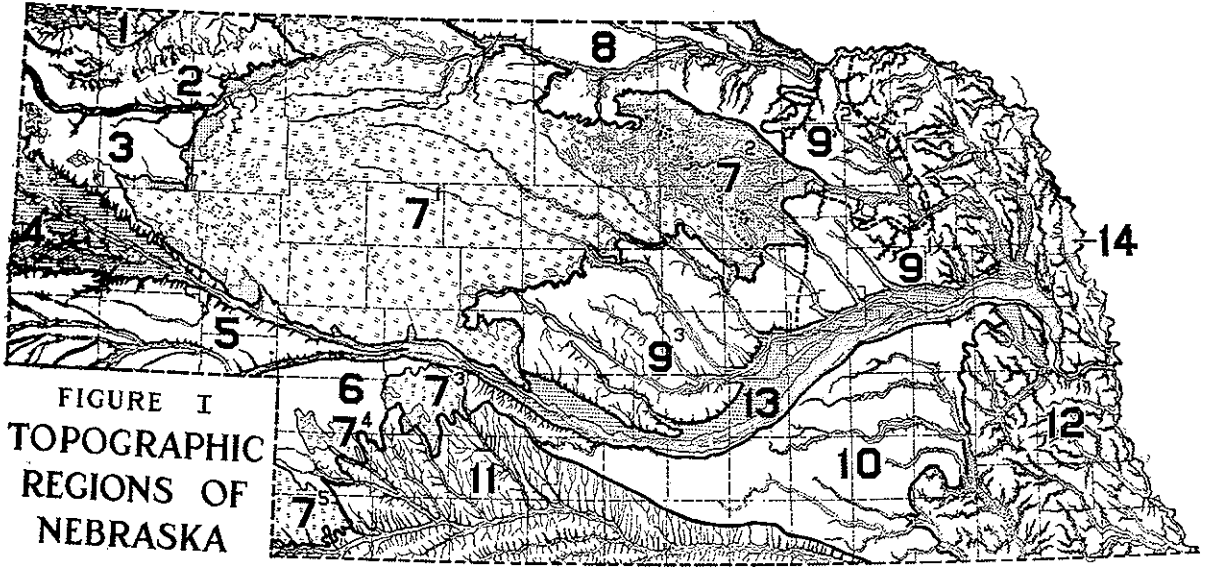

FIGURE 1.—The Topographic Regions of Nebraska: 1, Pierre Plains; 2, Pine Ridge; 3, Box Butte Tableland; 4, Wild Cat Ridge; 5, Cheyenne Tableland; 6, Perkins Tableland; 7^1 to 7^5, Sandhill Region and outliers of which 7^2 is the Prairie Plains area; 8, Northern Tablelands in which 8^1 is the Boyd Plain developed on Pierre Shale; 9^1, 9^2, and 9^3, Loess Hill Region; 10, Loess Region; 11, Republican Valley Region; 12, Drift Hill Region; 13, Platte Valley Lowlands; 14, Missouri River Lowlands.

Conservation of the Land and Water Resources of Nebraska

By G. E. Condra
Dean of the Conservation and Survey Division
University of Nebraska

INTRODUCTION

The people of Nebraska are conservation minded. They talk much about conservation, usually from the public point-of-view, and many of them realize that we must go beyond "talk fest" and apply the principles of conservation effectively to the specific problems of the state.

The basic purpose of conservation is to reduce the wastage of the natural and developed resources including human life. Its forward-looking objective is altruistic, embracing the best use that can be made of all resources and conditions for the greatest public benefit now and in the future. This requires a scientific approach, i.e., a factual background.

Failure and Successs. Nebraska is a young state, and fortunately the wastage of its basic resources has not been carried to a point beyond recovery. The conditions here are unlike those in some of the older states, where the people are becoming impoverished because the depleted lands will no longer produce the necessities of human life. In contrast with the unfavorable conditions that have been brought about in parts of the United States and some other countries, there are places in England, Germany, France, and Japan, where the lands have been farmed for hundreds of years with increased producing capacity. Nebraska should learn from the experience of other states and other countries.

Duties of Survey. It requires survey, research, and careful evaluation to establish applied conservation. This field of investigation is what the Conservation and Survey Division of the University has been assigned to cover under the statutes of the state. Consequently, this report, based on the activities of the Division and the experience of farmers and research workers generally, is made to the Legislature and citizens of the state in the hope of furthering sound conservation practice in Nebraska. Land conservation, other than agricultural, is not discussed in this paper.

THE CHANGED LANDSCAPE

Changed Conditions. Formerly the areas now classed as the agricultural lands of the United States were covered by prairie or forest, both of which have been largely replaced by cultivated crops. This change in landscape began in the east and progressed westward with our migrating forefathers who subdued the land with its prairie, forest, and wild life. Our predecessors had little technical guidance from Federal and State agencies regarding the management and use of land. They did the things that

were thought to be necessary and right under the conditions of their day which, in many cases, proved to be destructive with respect to matters of the future.

Erosion. Following the too general removal of the prairie in Nebraska, continued cultivation of the farm land and over-grazing of the remaining prairie caused the wastage of the soil resources. Under cultivation the sandy lands in parts of the state were wind eroded; the organic matter content of the soils was reduced; the topsoil of the hilly lands was removed in places by sheet erosion; the farms were broken by deep gullies caused by accelerated runoff; the bottomlands were silted or sanded locally with debris from the uplands; the clear streams gave way to muddy runoff, and with it all, much of the native wild life disappeared. A drama of man-made wastage was staged, resulting in ugly views at places.

Present Conditions. The removal of the black topsoil from the humid, hilly lands and the depletion of the organic matter generally in the state have disturbed the soil moisture relations, i.e., reduced the rate of absorption from the rainfall and increased the rate of surface runoff on certain types of land. The gullied lands drain away groundwater, lower the water table, and cause the loss of vast quantities of soil-forming materials. This wastage of the land and water resources has reduced the carrying capacity and value of the land in some areas.

CREDITS AND DEBITS

Wise Use. There are thousands of examples of successful farm management and right land and water uses in Nebraska. These and the many supplemental developments of country, town, and industry are the high lights of our landscape. They are the credit entries in the history of the state.

Unwise Use. Nebraska has not wasted its land resources to the extent that farms are being abandoned nor that there is a breakdown in the agricultural industry. However, mistakes have been made, as shown by the soil and water wastage and the reduced per-acre yields of farm crops. The unwise use of the lands has resulted in conditions which, if not more fully recognized and corrected, will retard the future development and welfare of Nebraska. This part of our history is now in the red. It presents many conservation problems and a challenge to the citizens of the state.

Recovery. The record of farming in Nebraska, from the beginning, has been too generally, but not everywhere, a "hit and miss" proposition with respect to the conservation of the land and water resources, but fortunately the unfavorable conditions that have developed are now recognized; means of recovery are fairly well known, and the adjustment of the agricultural enterprises to the climatic, soil and water conditions is underway.

ENVIRONMENTAL RELATIONSHIPS

Physical Diversity. Nebraska is physically quite diverse, a condition which multiplies the conservation problems. The altitude of the state ranges from 825 feet in the southeast to 5340 at the western border; the mean annual rainfall decreases from 34 inches in the southeast to 15 inches in the northwest. The state has three climatic belts—humid, sub-humid, and semi-arid—; fourteen topographic regions (Figure 1); twelve ground-water regions; and five distinct soil subdivisions, classed as the Silty Soil Region, the Mixed Soil Region, the Sandy Soil Region, the Loamy Soil Region, and the Clay Soil Region. On a basis of texture, color, compaction and other features, there are more than 350 types of soil within the state, grouped under about seventy series. References on the climatic elements and the various regions of the state are listed at the end of this report.

Oversight. When white men reached the area now known as Nebraska, they found that the plant life, animal life and the Indian held natural relationships, and that they were closely correlated with the environmental factors. The kinds, distribution and condition of growth of grasses, shrubs, trees and animals were long time indices of natural land and water use and of climatic influence. Until recent years, however, we have applied little that may have been learned from nature's visible relationships, and without much regard for the varied ecological conditions, have introduced farm plants and animals from regions generally unlike those in Nebraska, which procedure proved to be risky, sometimes unsuccessful, and was necessarily discontinued.

Meeting the Environment. The ecological conditions within the state are now quite well known as a result of close study by Dr. J. E. Weaver, Professor T. A. Kiesselbach, Dr. Frank A. Hayes and others, and the farm plants and animals are being selected and developed to meet the environmental factors of the state.

The Agricultural Experiment Stations have done much of value in plant breeding, crop selection, crop adaptation and animal husbandry, and the several agricultural associations of the state are furthering the cultural methods and farm enterprises that are suited to the conditions and needs of Nebraska. In other words, there is now a technical background for the practical application of conservation principles in this important environmental phase of agricultural development. The progress has been from a condition of chaos to that of coordinated adjustment.

CLIMATIC CONDITIONS

Correlative Factors. Solar radiation, the atmosphere, land, and the forms of water are correlative factors in the climatic conditions of Nebras-

ka. Their inter-relations produce the conditions of sunshine, temperature, cloudiness, winds, humidity, rainfall, evaporation, and storms, all of which change daily, seasonally, probably by periods of years, and vary regionally. Most people think of the climate of the atmosphere alone, not realizing, perhaps, that ecologists use the term more broadly, to include the climate of the soil, subsoil, streams, lakes, and sometimes the groundwater.

Essential Factors. Air, sunshine, water and soil are the factors essential for the higher forms of plant and animal life. There is air in the soil and in water, and there is water in the air, on the land, in the soil, and at various depths in the land. Heat and light penetrate the soil to shallow depths and the surface waters to greater depth.

Temperatures. The amount of solar insolation received at the surface of the land varies generally with latitude, time of day and the season, and more locally, with the exposure, degree of slope and proximity to bodies of water, and is affected by the degree of cloudiness and the nature and distribution of vegetative cover. The temperatures of the state range about as follows: atmosphere, from 40° below zero to 115° above; surface one inch of the soil, from below the freezing point to 150° above or more above zero; surface waters, from the freezing point to 80° or more above zero; and the shallower groundwaters from the freezing point to about 70° above zero, averaging about 55 to 58° most of the year.

High temperature, high wind velocity and low humidity further a high rate of evaporation and a high rate of plant transpiration. The amount, rate, duration, frequence and distribution of water precipitation have collectively a most important relation to the replenishment of soil moisture, surface water and groundwater. Deficiency in rainfall results in drouth which reduces excessively the soil moisture and surface waters, lowers the water table, and affects adversely the wild life and agricultural development.

Dominant Factor. Climate is the dominant factor in the development of Nebraska. Drouth and destructive storms which are off-center phenomena, may recur as future hazards. These hazards and the more normal features of the climate must be reckoned with on a factual basis. Apparently the climate, all elements considered, is not deviating from its usual course, yet our popular views of the matter may be influenced by a short-time view, i.e., by the position we occupy in a short cycle.

Man's Power Limited. Man cannot control insolation (light and heat from the sun), the general movements of the atmosphere or the amount of rainfall, but he can modify very locally the distribution and effect of sunshine, temperature, humidity, and evaporation and can influence the natural disposal of rainfall, surface waters and groundwaters.

Questions. The following questions are proposed for popular discussion:

1. What causes rainfall in Nebraska?
2. Why does the amount of rainfall decrease from east to west in Nebraska?
3. What are the economic relations of (1) fog, (2) dew, (3) sleet, (4) hail, (5) snow in Nebraska?
4. Under what conditions are heavy rainfalls and floods produced in Nebraska?
5. Does cultivation increase rainfall?
6. Do lakes and streams influence rainfall?
7. Does forest influence rainfall or any other climatic element?
8. Does drainage influence climate?
9. Do cannonading and volcanic activity cause rainfall?
10. Does the general use of electricity, radios or combustion engines influence climate in any way?
11. What is the variation in the length and distribution of the frost-free season in Nebraska?
12. How and in what ways does the U. S. Weather Bureau function as a conservation service in Nebraska?
13. How and in what ways do the weather and climate influence: (1) farm operations, (2) native vegetation, (3) cultivated crops, (4) fish, (5) birds, (6) insects, and (7) man?
14. Is the climate of Nebraska becoming more arid or more humid?
15. Has the climate of Nebraska changed during geologic time?

OUR WATER RESOURCES

Forms of Occurrence. Our water supply occurs in the atmosphere, on the surface of the land, in the soil and subsoil, and at various depths in the mantlerock and bedrock. Its forms of occurrence are as vapor, cloud or fog, dew, rain, hail, frost, snow, sheet water, soil moisture (capillary), lakes, springs, streams and groundwater proper (saturated). The water comes to Nebraska through the atmosphere from the ocean and returns to the ocean by surface runoff and by movement through the land and through the atmosphere. This water cycle, however, is modified by the sub-cyclic or local movement from the land and the surface water to the atmosphere and return whereby, as turn-over water, some of it is evaporated or transpired to the atmosphere and precipitated again and again as re-curring rainfalls, which means that the source of the rainfall of the state is both local and distant, the latter coming largely from the Gulf of Mexico and the Pacific Ocean.

Volume of Rainfall. The area of Nebraska is about 77,320 square miles or 49,484,800 acres and the mean annual rainfall according to the

U. S. Weather Bureau, is about 23½ inches or 96,907,711 acre-feet, which would cover a strip of land one mile wide the length of the state to a depth of 518 feet at the east end and 259 feet at the west.

Disposal of Rainfall. Part of the rainfall is on lakes and streams, becoming surface water; part of it is absorbed by vegetative cover, and that which reaches the surface of the land becomes surface runoff or is absorbed by the soil and subsoil. The rates of surface runoff and soil absorption vary with the vegetative cover, soil texture and structure, topography, intensity and duration of the rainfalls, and with frozen or unfrozen ground.

The amount of rainfall received and the nature of its distribution are important factors in the life of the state. A marked shortage, as in 1934, which was 33,970,773 acre feet between January first and September first, or an unfavorable distribution, as in 1936, causes severe drouth. The most effective rainfall is that from frequent showers of moderate intensity.

It should be observed that the disposal of the rainfall is influenced by the topography which causes it to drain from the hillsides and upper valley sides to the colluvial slopes, terraces and alluvial bottomlands. This phase of the runoff disposal of rain water works to the disadvantage of the hilly uplands and to the advantage of the smoother lowlands by giving to the latter soil moisture at the expense of the former.

Soil Moisture. The soils of the state differ greatly in their thickness, texture and structure and consequently in the rate of their absorption and capacity to store and hold moisture. About 40 per cent of the soil is pore space occupied by air, capillary water and plant roots. The soils with thick topsoils and abundant organic matter receive and hold relatively large quantities of water, whereas those with little organic matter are low in water-holding capacity. Sandy soils absorb much of the rainfall and pass it to groundwater storage, while the heavy soils shed relatively more of the rainfall as surface runoff.

Volume of Soil Moisture. At most, the soils afford only limited water storage which, without frequent replenishment from rainfall or by irrigation, is exhausted by evaporation, plant growth and percolation. Soil moisture, though of paramount importance in agriculture, is a mobile resource, subject to constant depletion, especially during hot weather.

Just what per cent of the state's mean annual rainfall passes through the soils has not been determined very accurately. There are places and conditions where most of it moves through the soil, whereas at other places, much of it becomes surface runoff and relatively less becomes soil moisture, especially so when there are heavy rains of long duration. For the state as a whole, however, it is estimated that more than 98 per cent of the rainfall passes into or through the soil, and the volume of water

held in the soil and subsoil at any time ranges between 5,000,000 and 13,-000,000 acre feet, depending upon the degree of replenishment and loss, the largest storage being after heavy rains in spring time and the lowest during late summer or a severe drouth.

Surface Waters. These are the natural streams, marshes and lakes and the storage in reservoirs. They are formed from rainfall, surface runoff and groundwater or by diversion and ponding and are reduced by evaporation, transpiration, percolation, discharge and water use.

Streams. The streams of the state vary considerably in quality of water and uniformity of flow, due mainly to the geologic, soil, and climatic conditions of their basins. Those fed mainly by surface runoff vary most in discharge and those heading in the groundwater of sandy lands, as in the Sandhill Region, are more uniform in flow. Most of the larger streams have been gaged at regular intervals for several years, and their discharge is quite well known.

Our streams are used for many purposes, as for stock water, irrigation, power development, rural and urban water supply, recreation and in a few cases for sewage disposal. Most of them contain fish and have relations to birds and other wild-life. Some are being developed for fish culture, and the Missouri River is being developed for navigation.

Our streams present problems relating to drainage, flood control, irrigation, power development, wild life, domestic water supply and recreational use.

Lakes. Counting those with areas of 15 acres or more, the state has more than 2300 lakes, marshes and artificial reservoirs. Most of the natural lakes and marshes are in the Sandhill Region. They are shallow; many of them are intermittent, and about 1000 of them became dry during the drouths of 1934 and 1936.

The intermittent lakes of the Loess Plain Region and of the tablelands of the western counties have little economic importance. They disappear mainly by evaporation and percolation and their beds supply some grazing and at places wild hay. They become the stopping places for migrating waterfowl, giving opportunity for hunting. The more permanent lakes and reservoirs of the state afford fishing, hunting, some stock water and recreation; many of the marshes are good habitats for wild life including muskrats, the pelts of which bring considerable revenue to the people of the state.

Area of Surface Water. The combined area of the intermittent lakes and marshes of the state is about 230 square miles; that of the more permanent lakes and marshes averages about 163 square miles, and that of the permanent streams is about 495 square miles. The maximum area of the surface waters of the state, not including floods, is about 890 square

miles. The average is about 640 square miles. The drouths of 1934 and 1936 reduced the combined area to about 300 square miles.

The area of the water surface of the state has been increased considerably the past few years by the construction of reservoirs in connection with water power, irrigation and erosion control works. When the reservoirs are filled, the irrigation and water power now under construction, or authorized for construction will add about 42,600 acres of water surface to the state. The evaporation loss from the reservoirs and other free water surfaces of the state is considerably more than the amount of direct rainfall they receive.

Volume of Surface Water. The amount of surface water, like the soil moisture, varies greatly through the year. Its mean volume is approximately 1,200,000 acre-feet, however, the amount that moves in the streams and occurs in surface storage during the year is much greater than this. Not including the discharge of the Missouri, the annual inflow from Kansas, Colorado, Wyoming and South Dakota through the Republican, South Platte, North Platte and Niobrara rivers and their branches is about 1,500,000 acre-feet and the outflow by the Niobrara, Hat Creek, White Creek, small branches of the Missouri, the Platte, Big Blue, Little Blue and the Republican is about 6,500,000 acre-feet. This shows that the ouflow exceeds the inflow by about 5,000,000 acre-feet, or in amount equal to slightly more than five per cent of the total volume of the mean annual rainfall of the state.

The annual discharge of the Missouri River varies between 25,000,000 and 52,000,000 acre-feet at Rulo. Of this there is a pick up of only about 5,450,000 acre-feet from Nebraska creeks and rivers.

What is Runoff? The term runoff is used by ecologists and erosion workers to denote the amount of water, measured in inches or percentage of the rainfall, that moves locally from the surface of the land as sheet water and small stream flow. It does not include the groundwater movement.

Engineers, however, make a different application of the term whereby all water discharge from a drainage basin or part of it is referred to as runoff. This includes both the surface runoff and the "runout" from the underflow of the land. It is not possible at all gaging stations to determine the total water movement from a water shed or basin, because all of the groundwater discharge may not be represented in the stream where a gaging is made, part of it passing as invisible underflow.

Groundwater Proper. This fills the porous mantlerock and bedrock from the water table down to the impervious platform. It is replenished by downward percolation from soil moisture derived from rainfall and from surface waters. The replenishment lifts the water table, and the

water passing into porous layers between inclined impervious formations develops artesian pressure. Seepage, springs, pumpage and drainage lower the water table of the shallow waters, and the heavy draft and wastage reduce the pressure and head in the artesian aquifers.

Quality of Groundwater. As a rule, the chemical quality of groundwater is due to the nature of the aquifer or formation containing it, and the amount of contamination decreases with depth. Much of the groundwater of Nebraska is medium hard and of good quality. In some of the deeper formations, it is quite heavily mineralized with iron, lime, salt, sulphur, etc.

Groundwater has importance as the source of rural and urban well water, for sub-irrigation and pump irrigation and as a source of springs and stream flow.

Amount of Groundwater. The thick, sandy mantlerock and the younger bedrock of the state have large water storage capacity. The amount of groundwater proper in the state is vastly greater than the combined surface and soil water. The volume of that which lies above the impervious bedrock is about ten times the mean annual rainfall or more than 90,000,000 acre-feet. This does not include the vast storage in the deeper formations, as the Dakota sandstones and older beds.

Movements of Groundwater. Sandy land absorbs much of the rainfall and passes it downward through the soil and mantlerock, building up storage above the impervious bedrock. This water moves underground with the gradient or slope of the water table to points of escape in the valleys. The rate of its movement averages about 2 or 3 feet per day. It takes years for this water to pass from central points in the upland to the seepage ways, springs and streams.

Water Table Level. Occasionally it is reported that the water level has lowered markedly at some place within a short time. Usually, however, such reports are based on observations made at wells after heavy pumpage and really mean local "draw down" and not the lowering of the water table generally.

The low rainfall of the recent drouths did not recharge the groundwater normally, and this, together with the loss by evaporation, transpiration, underflow and the excessive use of well water did lower the water table considerably in places. The water table level in the alluvial bottomlands dropped from one to three feet at many locations and 15 feet or more along-side the drainage ditches of the southeastern counties. In the sandhills, it lowered very little where the groundwater is deepest but dropped two to four feet at the lakes and in the valleys where the water table is shallow or exposed and evaporation and transpiration are most active.

The deep water table in the upland plains and tablelands does not fluctuate much, due to the slow underflow, lack of transpiration and evaporation, and the small use that is made of the water. At some places in the state, the limited amount of shallow groundwater is nearly exhausted during drouths.

Groundwater Depletion. Groundwater proper is less affected by drouth than soil moisture and surface water. The normal rainfall, as noted before, dropped off markedly between January first and September first, 1934, and the surface waters shrank to a low minimum, but the groundwater was depleted only about 4 per cent during this period, which means that it would require a drouth of long duration to reduce it to an alarming degree in most of the state.

Such groundwater shrinkage and exhaustion as there is during drouth, influence unfavorably the flow of springs and streams, the shallow well water supplies, and the lake levels. Its worst effect is the exhaustion of the drinking water supplies in certain small areas in the state.

Groundwater Level Record. The State Geological and Water surveys, cooperating with the Groundwater Branch of the United States Geological Survey, are measuring the water-table level and the water temperature in about 500 wells located in various parts of the state. These measurements are made at regular intervals and are recorded for study and future use. It is planned to continue this activity indefinitely for about the same reasons that the rainfall is measured and the discharge of streams is gaged.

LAND USE AND LAND PROBLEMS

Useful Materials. The land of Nebraska contains many useful materials, as sand, gravel, stone, clay, volcanic ash, some coal, and probably oil and gas. These are classed as mineral resources.

Cultural Use. The use that is made of land for highways, railways, airports, rural homes, industries, towns, cities, state institutions, game preserves and parks is considerable. These important uses and the mineral resources are not considered in this report.

Agricultural Land Resources. The main agricultural resources of our lands are the soils, water supplies, and the geologic materials from which the soils are developed. Their effective agronomic use is determined by the amount of distribution of rainfall, the length of growing seasons, the topography and erosivity of the land, and by crop adaptation and cultural methods.

The outstanding favorable conditions relating to the agricultural development of Nebraska are its extensive distribution of rich soil-forming materials in the mantlerock and bedrock and its widespread water-bearing formations. Probably no state is more richly endowed with these basic re-

sources. Our state is further characterized by its broad valleys and large areas of smooth upland which are occupied by deep, stone-free soils, making cultivation relatively easy and possible on a large scale. As noted before, climate is the controlling factor in land-use and the types of farming in Nebraska. The differences in topography, soils and climate cause diversity in the agriculture.

Survey and farming experience show that much of the state is adapted to agricultural use, that many mistakes have been made in farming, and that there are large areas of highly productive soil within the state. Some of the land is too rough or too sandy for cultivation and some is defective, due to lack of water supply, the presence of alkali, the lack of mineral fertility or other unfavorable conditions.

Land Surveys. All of the agricultural lands of Nebraska were filed upon and plowed before their adaptabilities were evaluated by survey. Within recent years, however, most of the state has been covered by the geological, soil, and groundwater surveys; about thirty per cent of it has been mapped topographically, and a detailed land-use map has been made of the whole state. The Agricultural Experiment Stations have accumulated valuable data on farm crops, land-use and other subjects. Soil erosion control work is being done, and the Agricultural Extension Service is carrying on an effective program in agricultural education. So we have the results of survey and investigation, the experience of farmers, and a public extension service for shaping the adjustments that should be made in the agricultural use of the lands of Nebraska.

Many bulletins on geology, water supply, soils, crop adaptation and cultural methods are available for farmers and others. They are obtainable through county agricultural agents, the College of Agriculture and the Conservation and Survey Division.

LAND-WATER CONSERVATION PROBLEMS

Most of this part of my paper is a review of problems involving both land water, hence the heading Land-Water Conservation. It is little more than a summary of the relation that conservation must necessarily hold to the future development and use of the state's land and water resources.

Soil Moisture. The soils, as noted before, shed and absorb rainfall. Their capacity to receive, hold and release moisture to the growing crops is a dominant factor in plant growth. Some soils are drouthy by nature and others are said to be drouth-resistant, yet the fact remains that in parts of the state cultivation causes them to become more drouthy, whereas by effective tillage practice and better systems of crop rotation more of the rainfall might be caused to enter the soils and less of it allowed to run from the soil where it is most needed.

Growing plant crops require much moisture, without which they wilt and fail to mature. Consequently, it is imperative that effective means be used to conserve soil moisture, as outlined later in connection with erosion control.

Humus and Nitrogen. These, developed from organic matter, were in the virgin soils of the state in relatively large amounts, but according to the investigations of Dean W. W. Burr and Professor D. L. Gross of the College of Agriculture they are being reduced under cultivation to a considerable degree in some soils, as shown by decreasing crop yields.

The replenishment and maintenance of the organic matter content of the agricultural soils in parts of the state is a big problem. Legumes and manures have been used for this purpose, with varying degrees of success. Alfalfa, which depletes the soil moisture at a rapid rate is our best humus and nitrogen-building crop, is giving way to sweet clover on the uplands, and is increasing in acreage on the irrigated and sub-irrigated lands. This means that it should not be grown in long rotations except where there is abundant soil moisture.

Use of Mineral Fertilizers. Nebraska soils, as a whole, have not become deficient in mineral nutrients to the point where commercial fertilizers are used very generally, nor is this condition likely to change very much in the near future because the soils are relatively rich in the essential mineral content. There are places in the southeastern counties, however, where they become rather acid or sour, and liming of them caused increased yields.

Experimental work by Professor J. C. Russel of the College of Agriculture shows that some sandy soils and those containing large amounts of alkali respond favorably to phosphate fertilizer and that the beet and potato crop yields of the state are increased very perceptibly by the use of mineral and organic fertilizers.

It is evident that fertilizers can be used more beneficially in the state than is generally supposed, and it is true that they should be selected and applied to meet the specific requirements of the soils and crops.

Land Problem Areas. Much of Nebraska is naturally suited to agriculture, but several areas of the state have defective features. The main kinds of land requiring amendment or adjustment in their agronomic use are as follows:

1. Badlands with practically no soil, 56 square miles or 35,840 acres.
2. Rough stony lands with little or no soil, about 1015 square miles or 649,600 acres.
3. Tablelands with thin soil, drouthy due to the low capacity of the soil to hold moisture, about 2510 square miles or 1,606,400 acres.
4. Tablelands with sandy soil, subject to severe wind erosion where

the plant cover is not maintained, about 1810 square miles or 1,158,400 acres.

5. Sandhill Region and its outliers, sandy soil, subject to blowing where not grass-covered, about 22,451 square miles or 14,336,640 acres.
6. Shaly "gumbo" lands, drouthy and without much well water, about 750 square miles or 480,000 acres.
7. Loess canyon areas, too rough for cultivation, about 4,270 square miles or 2,732,800 acres.
8. Blufflands, topographically unsuited to cultivation, approximately 400 square miles or 256,000 acres.
9. Eroded hillsides and gullies of the Drift Hill and Loess Hill regions, approximate aggregate area, 1200 square miles or 768,000 acres.
10. Shallow claypan areas, with low available soil moisture, about 3540 square miles or 2,065,600 acres.
11. Small depressional areas, subject to alternate flooding and dessication, about 200 square miles or 128,000 acres.
12. Low-lying bottom lands with sandy soil, shallow water table and occasional flooding, about 1260 square miles or 806,400 acres.

Badlands. These are excessively eroded small areas of Tertiary beds known as the Brule clay and the Chadron formation. They occur in northern Sioux and Dawes counties and at a few places in the North Platte and Pumpkin Creek valleys and are nearly barren of vegetation. Their erosion and barrenness are due to the uniform fine texture of the soft formations and the rapid surface runoff which has a high ratio to the rainfall.

Just how to reclaim the badlands is not known. They afford some grazing in places.

Rough Stony Lands. These occur principally in the Pine Ridge escarpment, Wildcat Ridge, at the borders of the tablelands and locally along the Missouri, Republican, Big Nemaha and lower course of the Platte. They were eroded on the Tertiary sandstone, Niobrara chalk, Dakota sandstone and the Permian and Pennsylvanian limestones.

This type of land is too stony and too rough for cultivation. It is best suited to grazing and forest growth. In places it is quite scenic due to the topography and forest cover.

The Federal Government is purchasing large areas of rough stony lands in the Pine Ridge Region for use in forest and game development and preservation.

Springs issuing from roughland canyons are useful in the lower border land areas.

Tablelands with Thin Soil. This type of land occurs widely in the tablelands of the western and northern counties. It is rolling to rough. The soils are classed chiefly as Epping and shallow phases of the Rosebud and Holt. They do not have the capacity to hold moisture sufficient for cultivated crops except during the most favorable years.

Some of the land is now idle, presenting a problem in management and use. When the soil on this land becomes dry and incoherent, much of it is removed by wind erosion, exposing the bedrock in places, but the remarkable feature of the land is its rapid recovery with increased rainfall. No doubt a considerable part of this kind of land should be seeded to native grass and used for grazing.

Tablelands with Sandy Soil. This type of land is widely scattered in the tableland regions and along the borders of the Sandhill Region. It is rolling to rough, and drouthy due to the rapid sub-drainage of the rainfall. Much of it has been farmed but with poor success except where plant cover is retained to hold the soil against wind erosion. The soils include the sandier and less stable types of the Rosebud, the more gravelly and sandy Tripp soils, and all of the Dickinson and Anselmo types and the Valentine soils of the tablelands and bordering the Sandhill Region.

Considerable areas of this kind of land are now out of cultivation, regaining their original prairie sod, which will require several years. The main problem here is the maintenance of grass cover.

Sandhill Areas. The conditions here are summarized as follows: Mantlerock and Bedrock: porous, extending to depths of 300 to 800 feet and resting on impervious beds; topography: hilly, modified by basins and valleys; soil and subsoil: sandy; rainfall: 17 to 24 inches, decreasing westward; natural plant cover: grass, small shrubs and clumps of trees; rate of rainfall absorption and downward percolation: high; surface runoff for about 90 per cent of areas: nil; groundwater storage: very great with high-lying water table; groundwater runoff: relatively high, making streams with uniform discharge; lakes and marshes: 2,000 or more, shallow, the depth varying with height of water table.

The sandhill areas are naturally prairie land. Formerly, plowing and over-grazing of them resulted in much wind erosion (Figure 2). The land is well suited to grazing and is now used primarily for cattle raising, the hills affording pasturage, the basins and flats producing hay for winter feed, and the shallow groundwater supplying well water.

The minor uses of the sandhills areas are for forestation, about 30,000 acres having been planted by the Federal Government and many groves by land owners; for Federal wild life preserves, about 78,000 acres; for wild life sanctuary, as for ducks, grouse and prairie chickens; for State recreational areas; and for groundwater storage from which uniform live streams

issue and are developed outside the region for power, recreation and wild life.

The main conservation problems in the sandhill areas involve the maintenance of uniform grass cover on the hills, the maintenance of the most favorable depth of water table in the hay flats, the preservation of the lakes and the conservation of wild life. Ranch management has assumed a high degree of adjustment and standardization in these areas and only high grade animals are raised.

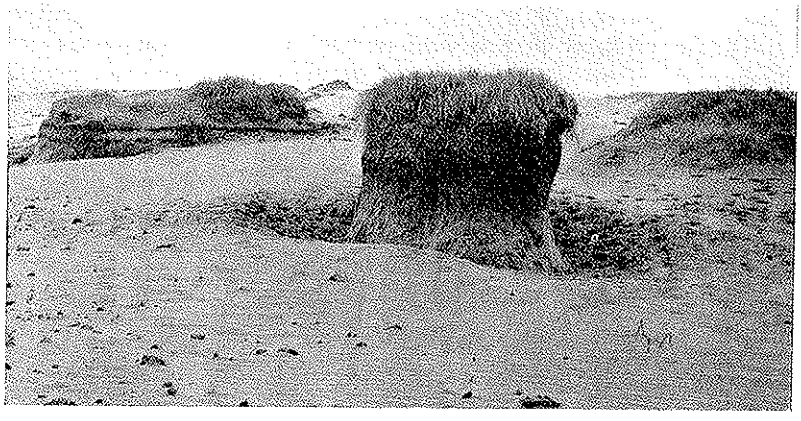

FIGURE 2.—Wind-eroded sandy land in Holt county.

"Gumbo" Land. An area of about 600 square miles of shaly "gumbo" land in northern Sioux and Dawes counties is defective for cultivation. Its natural conditions are: Shale (Pierre), extending from the surface to a depth of 1200 feet or more; topography: hilly, modified by small valleys; soil: thin, clayey, known as dark "gumbo"; rainfall: 16 to 18 inches; natural plant cover: grass and shrubs; rate of rainfall absorption and water penetration: low; surface runoff, rapid and relatively high; groundwater storage: little and of poor quality except at depths of 2,000 feet or more.

This type of land, of which there are small tracts in Keyapaha, Boyd and other counties and larger areas in the Dakotas, has been badly managed. Its main drawbacks are the absence of well water and the scant soil moisture during dry years. Too much of the land in Sioux and Dawes counties has been plowed and large areas of it are being abandoned as farm land.

This land presents a problem in resettlement, involving the location of ranch buildings where drinking water can be had and where there is land suited to cultivation. In its natural condition, the land grows quite

uniform stands of grass suited for grazing, but its over-grazing is very objectionable. Generally the land can be used to best advantage by fencing large pastures, ponding stock water from the surface runoff and by conservative grazing. Some of the gumbo land produces vegetation injurious to live stock.

Loess Canyon Areas. These roughlands occur principally in the Republican Valley Region, along the south side of the Platte Valley between North Platte and Lexington, in northern Dawson county, and in Custer county. They are modified by small loess plains. The prevailing soil is the Colby silt loam.

The canyon floors of these areas are narrow, usually grass-covered and produce native hay. The canyon walls are steep, locally bare and generally grasscovered. Most of the small irregular loess plains lying between the canyons are farmed.

FIGURE 3.—Rill erosion as a result of up- and down-hill farming.

No doubt the canyon floors should not be plowed because the native grass sod prevents erosion, and the areas generally should be left retained in native grass for conservative grazing. Again, farming on the small loess plains should not be extended too close to the edges of the canyons because it causes the widening and lengthening of the canyons.

Eroded Drift Hills and Loess Hills. The up-and-down-hill cultivation of the steep slopes of the Drift and Loess hills has caused extensive sheet erosion (Figure 3) and gullying (Figure 4), which have reduced the pro-

duction and value of the land. It is evident that contour tillage (Figure 5) and strip farming should be practiced more generally here in order to prevent the depletion of the land.

Under present conditions the black Moody and Marshall soils are rapidly giving way through erosion to the light colored Knox and Crofton soils, and the dark Carrington soils are giving way to the shallow Shelby soils.

FIGURE 4.—Typical gullied land in northeastern Nebraska.

The topsoil has been eroded from many of the steep slopes in these regions, but fortunately there is thick soil-forming mantlerock material. By proper management the land can be reclaimed. Also, the gullies can be filled and grassed as sodded sloughs as they were originally.

The Soil Conversation Service is studying the methods to use in the prevention of further destructive erosion in these regions and is improving thousands of scarred hillsides and gullies. Apparently the steeper hill slopes here should be seeded to permanent grass.

Bluff Lands. These are topographically similar to the Loess Canyons. They were developed on drift and loess deposits which overlie bedrock formations. The soft chalk rock outcrops along the Missouri from between northeastern Boyd county to northeastern Cedar county are also known as bluffs.

FIGURE 5.—Contour farming on gently rolling land.

The bluff lands occur along the Missouri and in the lower course of the Platte and its main tributaries. They are either grass-covered or forested and are used locally for fruit farming. They are not suited to general farm cropping where the slopes exceed about 20 per cent. Much of this land should be kept under grass and tree cover, for use in grazing, parks and recreation areas. There are many fine vistas from the bluffs along the Missouri and the Platte, known as Devil's Nest, Black Bird Hill, King Hill, Queen Hill, Child's Point, Jones Point, Goose Hill, Indian Cave, Iowa Point and Pawhuk. They might be made the objective places for the development of the scenic and recreational features of the blufflands.

Claypan Areas. These are the areas of Crete and Butler soils in south-central Nebraska, Pawnee soils in the southeastern part of the state and Dawes soils in the western counties. They comprise about 3,540 square miles or 2,065,600 acres. The topography is nearly level to gently rolling uplands where downward soil leaching has greatly increased the compaction of the subsoil. The surface runoff is relatively slow and moisture absorption is fairly high. Fine clay particles carried down from the topsoils by percolating water have "plugged" the upper subsoil horizons to such an extent that they have become extremely impermeable and limit the effective soil moisture storage. The water available for crops is con-

fined largely to that part of the soil above the claypan, usually above a depth of 12 or 18 inches. Very little of the local rain penetrates to deep water storage.

Thus far no effective methods have been devised that notably increase the amount of moisture annually stored in these soils. Small grains which make the best use of the rather limited moisture supply are grown chiefly. They mature early in the summer, usually before the topsoil moisture stored during the preceding fall and spring is exhausted, and they are less subject to severe drouth injury than corn and alfalfa both of which require moisture in relatively large amounts and for longer periods.

As indicated above the dominant limiting factor in the use of these soils is the claypan subsoil and its unfavorable effect on the soil moisture storage. Otherwise the soils are well suited for general farming as shown by their production during seasons of normal precipitation. They are defective only during droughts. There is no water erosion problem here but some damage is done by wind erosion during dry years when the vegetative cover fails.

Conservation measures on these soils are confined largely to adjustments in the cropping practices designed to make the best possible use of the limited soil moisture supply. According to present plans a part of the area occupied by the Crete soils is to be irrigated with flood water from the Platte.

Depressional Areas. These small, inward-draining basins occur on the Loess Plain, Western Tablelands and on terraces. The rainfall accumulates in them, usually in spring time, making the use of the land uncertain for farming during dry years and impossible during wet years. The temporary lakes are not of much use because little of their water percolates through the heavy claypan and mantlerock to groundwater storage and most of it evaporates, leaving bare lake beds which soon grow up to smartweeds and other undesirable plants.

Various schemes have been proposed for withdrawing the water from these depressional areas, as by dynamiting the claypan, sinking wells to the water-bearing sands and gravels, and by surface drainage. Some of the depressions located where the water could be removed, have been drained by canals, but the other methods of reclamation have failed. No attempt has been made to use the water of these lakes for irrigation, either by pumping or by spreading that drained from the lakes.

Low-Lying Sandy Bottomlands. These are the low sandy bottomlands bordering the streams, the sanded areas deposited by floods and the sand and gravel wash on the bars and beds of streams and in their abandoned channels. As a rule, the water table is shallow, all of the land is subject to flooding from high stages of the streams and much of it is sub-irrigated. The principal soil series is the Cass.

The smooth, sandy flood plains, which occur quite extensively in the valleys of the state are natural prairie lands and should be conserved for hay production and grazing. They are the state's best native hay lands and are better suited for this purpose than cultivation. The shallow water table is their controlling factor.

The reclamation of the sanded lands along the Republican, Platte and Elkhorn rivers is a subject for technical study and solution by practical demonstration (Figure 6). Very good results are being obtained by deep plowing where the sand cover is thin and the covered soil can be lifted

FIGURE 6.—Silt and sand deposited as a result of erosion of the upland.

and incorporated with the sand. In places where the sand cover is thick, the sanded land soon becomes covered with thick stands of weeds, cottonwoods and willows and by gathering windblown material and silt from overflows, builds a soil on the sand wash. Some farmers seed the thinly sanded land to sweet clover and thus further soil-building.

The large areas of river wash along the Missouri River formed by channel change incident to the development of navigation present a problem in land-use. Since the river is to be held to its new channel, there will be constant wash onto the sandy land from the uplands and by local overflows, which, within a few years, will build good agricultural land where there are now sandbars and stretches of abandoned channel. The easiest way to reclaim these sand wash areas will be to allow them to grow to weeds, willows and cottonwoods until a soil is developed.

IRRIGATION RECLAMATION

Irrigation is the spread of surface water or groundwater upon dryland soils largely for increasing agricultural production. It has become an important means of developing our sub-humid and semi-arid lands, limited only by the availability of water and the suitability of the soils.

It is the purpose of the state to develop its irrigation possibilities as fully as possible but with every safeguard against failure. Since the amount of our land suitable for irrigation far exceeds the required amount of water available for reclamation, it has become necessary for the state to control the allocation and spread of the water in order to secure its most effective beneficial use.

Kinds of Irrigation. The kinds or forms of irrigation, based on the source of water and the way it is spread, are: (1) Canal irrigation, from streams or impounded runoff; (2) pump irrigation, with groundwater or surface water; (3) sub-irrigation, with groundwater supplying capillary water to plant roots; and (4) spray irrigation, spread through pipes or tubing. Pump irrigation and spray irrigation are essentially alike, differing only in the method of spreading water.

Amount of Irrigation. The extent of irrigation in Nebraska is approximately as follows: (1) From canals with water diverted from streams, 570,000 acres; (2) by pumping from groundwater and streams, 60,000 acres; (3) by spraying from rural and municipal water supplies, 40,000 acres, and (4) by sub-irrigation from groundwater, 1,300,000 acres; total by surface-irrigation and sub-irrigation, about 1,970,000 acres, or about 4 per cent of the area of the state. This area is being extended by new developments and is being reduced locally by the removal of small undesirable tracts from the existing districts.

Drouth Relations. The demand for irrigation is greatest during dry years, especially on the soils that have a low capacity for moisture storage. Consequently, more land of the sub-humid areas is placed under irrigation during and immediately following drouth, and there is a tendency not to irrigate it during wet years, whereas, in the semi-arid districts, irrigation is more necessary and is relied upon every year. The severe drouths of the past few years, i.e., from 1894 on, have been accompanied by the development of public sentiment for irrigation and the installation of new projects.

Present Conditions. The people are now irrigation minded, due to (1) the drouths of 1934 and 1936, (2) successful production in the irrigation districts, and (3) the availability of Federal funds for the construction of new projects. More consideration than in the past is being given to the dependability of the water supplies, suitability of the soils, economic factors and the methods used in irrigation farming. However, many people of the state do not yet realize that as a rule irrigation is most successful

where the farmers rely on it every year more than on rainfall, and that sometimes it is most unsuccessful in the sub-humid areas, where the farmers hope for rain and do not irrigate at the proper time.

Water Storage. At first, all irrigation in Nebraska was with water diverted from streams during the irrigation season, but because the stream flow was low when water was most needed, it became necessary to conserve the nonirrigation season flow and the flood flow of the streams in order to obtain dependable water supplies. This condition lead to the construction of regulating reservoirs, as the Pathfinder and Guernsey in Wyoming, and Lake Alice, Lake Minatare and others in Nebraska, making a total reservoir storage of about 1,300,000 acre-feet in the North Platte Valley in Wyoming and Nebraska prior to 1936. In contrast with this, the combined capacity of the irrigation reservoirs now building or being considered for approval and construction in Nebraska is about 2,721,500 acre-feet.

The Pathfinder storage is released during the irrigation season to flow on the bed of the North Platte to near Whalen, Wyoming, where it is diverted for some irrigation in that state and much more in Nebraska. This and other diversions build up an average of about 3,000,000 acre-feet of groundwater storage in the terrace and slope lands of the valley, from which there is all-year return-flow to the river. By reservoir and groundwater storage the flow of the upper course of the river is stabilized and utilized.

The Platte River flow is now being controlled by storage farther down-valley. This development will supply water for the irrigation districts between North Platte and Grand Island and will stabilize the flow for power developments.

Sandhill Storage. Nature gave Nebraska, in the sandhills, the most ideal water storage area in the Great Plains Region. The amount of groundwater here is more than 500,000,000 acre-feet, which is equal to about 500 times the capacity of the Pathfinder reservoir. This water is re-charged by rainfall and is released all year at uniform rate to streams and invisible underflow to valleys. It is one of our most important resources.

The area of the Sandhill Region lying between the Platte and Niobrara valleys is about 19,332 square miles or 12,372,480 acres on which the annual rainfall is about 21,600,000 acre-feet, most of which enters the ground. In about 10 per cent of this area the amount of water passed to the atmosphere by transpiration and evaporation exceeds the rainfall, and in another 10 per cent there is slightly more runoff (run out) than rainfall, whereas for about 80 per cent of the region water is released by under drainage

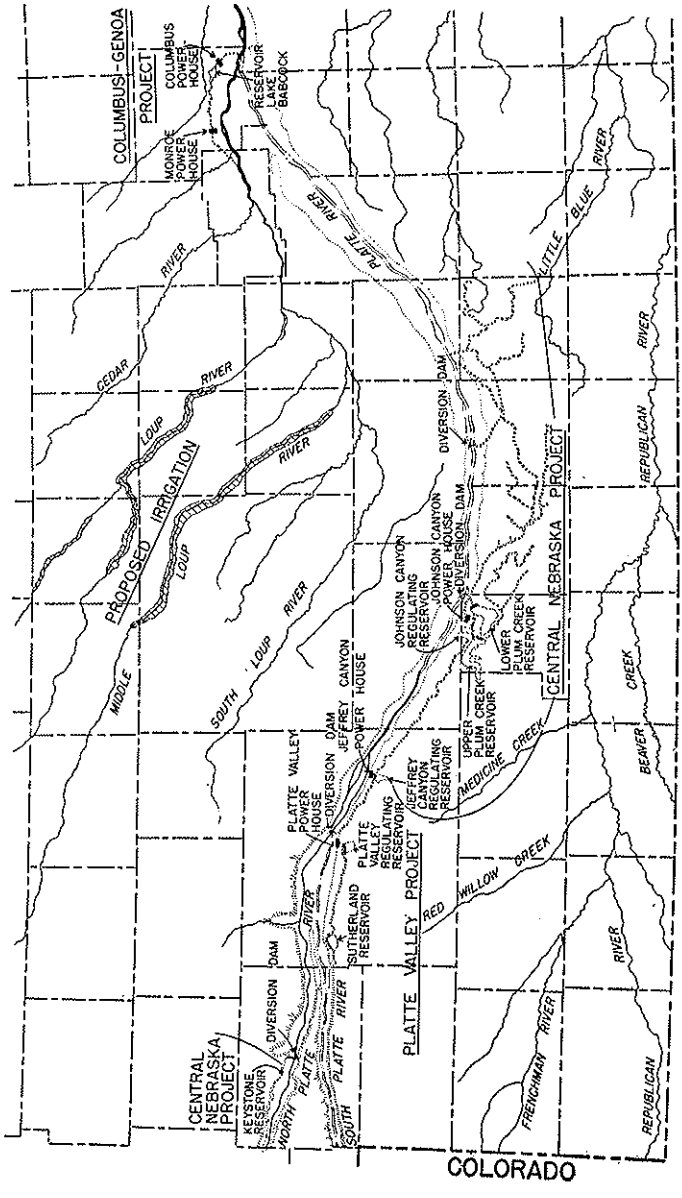

FIGURE 7.—Location of new irrigation and power projects in Nebraska.

and streams at the rate of 20 to 25 per cent of the volume of the rainfall, in the approximate amount of about 4,000,000 acre-feet per year.

The annual contribution of sandhill groundwater to the Platte Valley in the stretch between Bridgeport and Gothenburg is more than the amount stored each year in the Pathfinder reservoir and the outflow to the Niobrara, Elkhorn and Loup valleys is equal to three times the capacity of the Pathfinder reservoir.

Fortunately the sandhill water is to become a dominant factor in power and irrigation developments. Its non-irrigation season stream flow, as along the North Platte, is to be impounded for irrigation and other uses.

New Irrigation Projects. The following large self-liquidating Federal projects (Figure 7) are building or have been approved for development: (1) Central Nebraska Public Power and Irrigation District, known also as the Tri-County Project; (2) Middle Loup Public Power and Irrigation District; (3) North Loup Public Power and Irrigation District; and (4) the Platte Valley Public Power and Irrigation District, known as the Sutherland Project, which is being developed primarily for power but will deliver supplemental water to irrigation districts.

The areas to be irrigated by the three new districts listed above are about as follows: (1) 295,000 acres; (2) 45,000 acres; (3) 60,000 acres; total about 400,000 acres or more. The allocation for number (1) was 557,000 acres, but by decision of the Supreme Court, based on a statutory enactment which prevents diversion from the Platte Basin, about 40 per cent of the area allocated must be withdrawn from the district. This will leave about 295,000 acres unless more land within the basin is included to replace what is withdrawn from the original project.

Sandhill groundwater is the important regulatory factor in the projects on the Loup rivers, because it gives a uniform flow to the streams where they leave the sandhills. However, in their hard land courses, the surface runoff to the rivers is not very uniform and might be regulated by reservoir storage.

The storage dam to be built by the Tri-County project in the North Platte Valley about 4¾ miles above Keystone, Keith county will cost about $10,000,000. Its length is to be a little more than two miles and the height about 160 feet. The storage capacity of the reservoir is to be about 2,000,000 acre-feet which should control the non-irrigation season flow and the so-called flood flow of the river. This dam, like the Pathfinder and Guernsey dams in Wyoming, is intended to be a major stabilizing factor in the control of the Platte River and the use of lands in the valley.

The total allocation of Federal funds to subsidizing the irrigation, power and transmission projects building in Nebraska is more than $45,000,000.

Pump Irrigation. About 1700 pumps were operated in the state this year (1936) in lifting water from wells and streams to irrigate about 60,000 acres of land, and there is considerable additional land in the state that could be pump-irrigated under proper management. It is also evident that this kind of irrigation should not be undertaken without careful consideration of the quantity, quality and depth of groundwater, the suitability of the soils, the cost of installation and maintenance, and the economic benefit that would accrue from such development.

I will now answer some of the questions on pump irrigation that are often received at the office of the Conservation and Survey Division:

1. Q. What has the University of Nebraska to offer in surveys and service on the pump irrigation possibilities of the state?

   A. The Geological, Soil, and Water surveys of the Conservation and Survey Division of the University have been active for several years in the study, mapping, and description of the geology, soils, streams, lakes, and groundwaters of the state, and the Division also serves the state as an information bureau regarding the state's resources and their development.

   Pump irrigation has been studied by the College of Agriculture and its associated Agricultural Experiment Stations and the data obtained through these investigations and the surveys noted above are used in the Agricultural Extension Service. A recent bulletin on pump irrigation at the North Platte Station may be obtained free upon request by farmers and others.

   The county agricultural agents of the state are conversant with the various services of the University. Persons interested in pump irrigation should consult them regarding the proper agencies at the University to contact for information and guidance in pump irrigation.

2. Q. What is the best procedure for a farmer to follow to learn whether he has pump irrigation possibilities on his farm?

   A. The farmer should, by investigation and by reliable assistance from others, determine the following:

   (1) Whether his soil is suited to irrigation.

   (2) Whether there is adequate suitable water for irrigation and the probable amount that could be pumped from a well or a stream and at what depth.

   (3) The type of well or wells to put down, the kind of power to use and the operation costs.

   (4) The total cost of installation of pumps, casing, screens, power, etc.

3. Q. What kinds of soil are suitable for irrigation and which are not?
   A. The light, sandy soils, because of their rapid subdrainage, are not suitable for irrigation. Their moisture holding capacity is low. Water spread upon them passes down to the water table quite rapidly.

   The deep ~~soil~~ silt loam and the very fine sandy loam types are suitable. Our best irrigable soils are the silty types of the Wabash, Waukesha, Hall, Tripp, Marshall, Moody, Carrington, Hastings, Holdrege, Keith, Dunlap, Yale, Rosebud, Dawes, and Epping series. These are described in county soil survey reports.
4. Q. Where can information on the groundwate formations and the availability and suitability of water be obtained?
   A. From the Water Survey Department of the Conservation and Survey Division, University of Nebraska, Lincoln.
5. Q. Where can information on types of wells, pumps, and cost of operation etc., be obtained?
   A. From the Rural Engineering Department of the University of Nebraska, Lincoln.
6. Q. How can the amount of water and its availability for pumping be determined in the most economical manner?
   A. As a rule, the farmer knows whether a stream is permanent or intermittent and about how much of its water is available for pumping. He can measure the height to which this water would be lifted.

   The determination ~~and~~ of the amount and availability of groundwater requires prospecting. This should be done in order to determine the depth and thickness of the water-bearing beds and the nature of the materials at all depths in which the water occurs. Fine, water-filled sand makes weak wells and thick deposits of water-filled gravels with wide distribution make strong wells. The complete section of the water-filled ground should be determined for use in making the best location of a well, the type and diameter of well to be sunk, and at what depths to perforate the casing and place the pump.

   It is not safe to proceed to make a well and install pumps, etc., without first knowing the capacity of the ground to produce the necessary quantity of water. Persons engaged in making irrigation wells put down the test holes at a reasonable cost. They save samples of the materials obtained from all depths, and by a study of them can plan the kind of well to be made if the conditions are favorable. The Water Survey assists in these matters.
7. Q. From what depth can water be lifted economically for irrigation?

A. The depth varies greatly with the kind and value of the crop grown, the cost of installation and the cost of power for pumping. Professor E. E. Brackett and Ivan D. Wood of the College of Agriculture can answer this question in detail.

8. Q. Is pump irrigation desirable on farms already under canals but with inadequate water?

A. Yes and no. There are places in the state where the water obtained by gravity flow from streams and reservoirs is not fully adequate every year and the groundwater could be pumped beneficially, but much of the pumpable water in some of these areas passed into ground storage by percolation from the existing canals and at the expense of the irrigators. Consequently, there is a point here for consideration by those who allocate the surface waters and the groundwaters for their most beneficial use. As a rule, it is not equitable for a land owner in an organized district to reserve his his land for pump irrigation, especially if the groundwater storage results from the canal irrigation and the land in question could be served by this canal.

9. Q. Are small reservoirs preferable to wells as a source of irrigation water?

A. The shaly lands of the state are without available well water and reservoir storage is the only means of supplying irrigation water to them. All told, small reservoirs are not very satisfactory because they soon become filled with debris resulting from erosion. Generally, groundwater and permanent streams are preferable for pump irrigation.

10. Q. Will the average farm well supply enough water to irrigate a farm garden?

A. As a rule, no, unless the garden is small. Farm wells vary greatly in their pumpage capacity. Most of them are made and equipped only for light pumping, as for the household and the livestock, whereas the irrigation requirements are much greater. However, the need now, in most of Nebraska, is for stronger farm wells to be used for the usual purposes and for the irrigation of lawns, trees and gardens.

Spray Irrigation. Although spray irrigation has importance in the state, the people generally do not realize that it is irrigation. The improved municipal water supplies at Lincoln, Omaha, Grand Island, Kearney, Superior and other cities make water available for the spray-irrigation of lawns, trees, golf courses and gardens. As given before, the total area that is spray-irrigated in the state is estimated as 40,000 acres.

Improvements should be made in spray-irrigation because much of the water so spread does not enter the soil and the roots of plants. Los Angeles, California, uses most spray irrigation. The methods used there, whereby the water is effectively applied, might be followed more generally in Nebraska. Our farmsteads, towns and cities lost millions of trees during the drouth of this year, which might have been prevented by the right use of water.

Sub-Irrigation. This, our cheapest irrigation, is subject to control and improvement. There are many places where the groundwater table can be held at the optimum depth for native grass, forest and cultivated crops. This can be done by the distribution of flood waters for the recharge of groundwater and by drainage control in which the water table is maintained at the desired depth.

There is extensive sub-irrigation on the low-lying sandy lands of our principal valleys, on the hay flats of the sandhills and in the Prairie Plains area of the sandhills. The total area of the sub-irrigated lands with shallow water table, is considerably greater than that under all other forms of irrigation.

Alfalfa is our principal sub-irrigated crop where the soils are silty to loamy and the water table is comparatively shallow. Native grasses do best where the water table is near the surface and corn, wheat and trees where it is at a moderate depth. The seepage lands with alkaline soils are best used for the production of native grass.

The sandy bottom lands and the sandy terraces conserve the rainfall by passing it to groundwater storage which facilitates sub-irrigation. In fact, sub-irrigated water is built up in this manner as well as from seepage from irrigation canals and streams.

Much of the middle course of the Platte Valley is sub-irrigated with water from local rainfall, with return flow from up-valley, with under flow from the sandhills, and in part from the river. The problem here is to maintain the groundwater table at the most effective depth for native vegetation and farm crops.

EROSION CONTROL SERVICE

Organization. The Federal Soil Conservation Service, in cooperation with the College of Agriculture and the Conservation and Survey Division of the University, is engaged in a soil and water saving program in Nebraska. The work began in March of 1934, in Boone and Nance counties and is now functioning through three demonstration projects and sixteen CCC camps widely distributed in the state.

Administration of the service centers in Dr. H. H. Bennett, Chief of the Bureau at Washington, Dr. N. E. Winters, Regional Director at

Salina, Kansas, and H. E. Engstrom, Coordinator for Nebraska. The State Advisory Board is composed of Dean W. W. Burr, Director W. H. Brokaw and Dean G. E. Condra.

The central office for the state is at the College of Agriculture, Lincoln. Employees of the service are classed under the heads: Administration managers, soil technicians, agronomists, agricultural engineers, biologists, clerical assistants, CCC enrollees, and relief labor. The administrative, technical, and clerical personnel are employed under Civil Service appointments.

Projects. The original demonstration project, established in Boone and Nance counties, with headquarters at Albion, operates on a selected area of 69,700 acres in the Plum Creek drainage area. Progress made on this project and adjacent lands to date is as follows: Area completed by detailed erosion survey, 81,937 acres; contour tilled, 9,777 acres; contour furrowed, 119 acres; strip cropped, 328 acres; terraces constructed, 329 miles; woodland planted, 977 acres; brush dams constructed, 3,723; permanent dams constructed, 309.

On the Douglas county project, with headquarters at Ralston, the work done to November 6, 1936 was: erosion survey, 8,648 acres; contour tilled, 598 acres; contour furrowed, 25 acres; strip cropped, 357 acres; terraces constructed, 6 miles; woodland planted, 38 acres; brush dams constructed, 329; permanent dams constructed, 24.

On the Otoe county project, headquarters at Syracuse, the progress to November 6, 1936 was: erosion survey, 6,375 acres; contour tilled, 531 acres; contour furrowed, 35 acres; strip cropped, 147 acres; terrace construction, 14 miles; woodland planted, 39 acres; brush dams constructed, 923; permanent dams constructed, 13.

Some control work is carried on by the Public Works Administration and on Resettlement projects.

Program. The complete soil erosion control program in Nebraska includes the following:

1. Gully control.
2. Contour farming.
3. Strip cropping.
4. Terracing.
5. Construction of farm ponds and reservoirs.
6. Winter cover crops.
7. Retiring steep and unsuitable land for cultivation from cultivation.
8. Systematic crop rotation.
9. Pasture and range land management.
10. Protection of woodlands and grasslands from fire.
11. Wildlife preservation.

CCC Camps. The Soil Conservation Service directs and supervises the soil conservation program of sixteen CCC Camps engaged in soil conservation demonstrational work in Nebraska. These operating camps are located in the following counties:

Cedar	Greeley	Cass	Gage
Washington	Butler	Johnson	Jefferson
Madison	Buffalo	Richardson	Thayer
Platte	Lancaster	Pawnee	Nuckolls

Each camp is administered by a Superintendent, three technical foremen, one clerk, one black-smith and mechanic. The normal enrollee strength in each camp is 200 men, but during the past few months, many of them have obtained employment in private and corporate industry, which has cut the enrollee strength to an average of 160 men per camp.

A resume of the progress in the field accomplished by the CCC Camps is as follows:

1. Cooperative agreements made	694
2. Number of acres under agreement	138,715
3. Acres erosion survey completed	188,775
4. Temporary dams constructed	7,615
5. Permanent dams constructed	519
6. Acres contour farmed	35,340
7. Acres contour furrowed	3,960
8. Acres strip cropped	3,290
9. Miles of terrace constructed	578

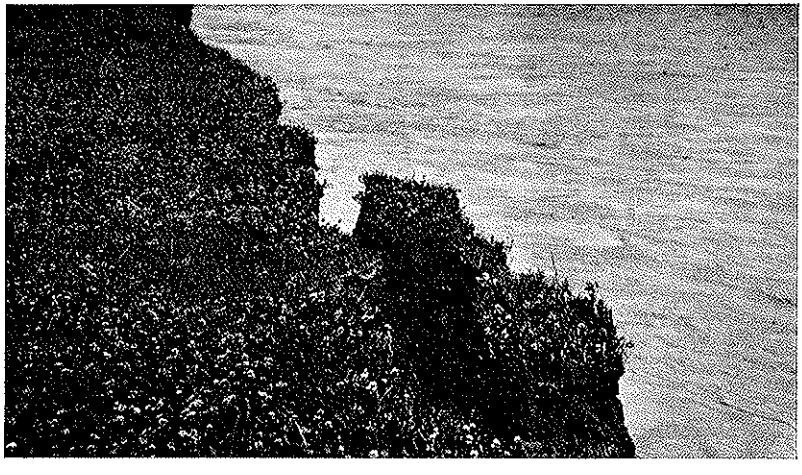

FIGURE 8.—Bank erosion along the Missouri River in Burt county.

Future Work. Evidently the Soil Conservation Service cannot be expected to do all the erosion control work in Nebraska. The CCC Camps are now decreasing in enrollees and may be discontinued with recovery, and the demonstration projects cannot be enlarged indefinitely. This means that within a few years the farmers must do the control work on their own farms with the technical assistance of extension workers.

AGRICULTURAL FORESTRY

Place for Trees. Trees, like the native and cultivated grasses, have an important though neglected role in the management and use of land. For very obvious reasons, we should grow more trees and shrubs on our farms, ranches, and rural school grounds. This will require an agricultural forestry program for Nebraska and the bordering states as an integral part of of the conservation program. It would constitute an important physical and social contribution toward the maintenance and improvement of agriculture within a vast, nationally important agricultural area.

Forestry Program. For the past thirty years the Federal Government has carried on a forestry program for the conservation of timber and other resources, mostly on Federally-owned land where forests occur naturally. However, the time has come when both agriculturists and foresters must realize that there is another phase of forestry which has to do with the proper management of agricultural lands, where the problems involved concern the relationship of trees to the maintenance and improvement of soil, the conservation of water, wild life, livestock, and those intangible social benefits relating to human comfort and the increased happiness of living.

Agricultural or farm forestry in Nebraska must cover a wide area with variations in climate, topography, groundwater, soil, population, and types of agriculture. Therefore, it is necessary that a sound program be provided not only for different types of planting, but also for different methods of application. For these reasons, such a program should be organized by that service of the government which concerns itself with the Nation's forest problems in general. Then, too, primarily from the standpoint of water conservation, there is a direct relationship between the Nation's large forest areas and general agriculture.

Cooperative Program. National, State, and industrial interests would be affected directly by such a program, and therefore the program should be on a truly cooperative basis; first, in the various Federal departments involved in conservation; second, with the state to which the program applies and where in most cases individual programs are now in operation through the College of Agriculture and State Departments of Forestry; and third, the commercial nurseries which are now and have been for years interested in this type of development and improvement work.

Basis of Program. The program should be on both a project and educational basis—on a project basis where necessary to improve the physical resources and stabilize agriculture on areas sorely in need of such work, and where deterioration should be checked at the earliest possible moment; on an educational basis because neither the National government nor the State can carry a program of this kind through to completion without the support and assistance of the individual land-owners. We cannot overlook some fundamentals in human nature which experience has proved will not be changed. The farmer owning the land where tree planting is done must feel the personal responsibility in the project, be a party to the general planting procedure and share the costs.

Kinds of Trees. Much has been learned during recent years regarding the kinds of trees and shrubs that grow and survive under the Nebraska conditions. This means that in the future only those species that are adapted to the soils, climate, and water supply should be planted in Nebraska.

The recent drouths killed many of our trees, which are being cut for fire wood. Unfortunately, however, the tree-cutting program is being carried on rather carelessly, including valuable trees which should be preserved.

Legislation. Present legislation seems to be inadequate to conduct a tree-planting program such as is needed. There should be legislative authority broad enough to include all phases of rural tree planting in Nebraska, and ample authority to include full exercise of cooperative effort between Federal, State, counties and municipal agencies, and individual and private institutions. The statutes of our state place the forestry activities under three agencies, viz; the Conservation and Survey Division, the College of Agriculture and the Game, Forestation, and Parks Commission. It seems that the law should be amended to retain the research and survey phases of the work to the Conservation and Survey Division, assign the general educational and agricultural program to the Forest Extension Service of the College of Agriculture, and restrict the planting on the State-owned lands, as the recreation areas and State parks, to the Game, Forestation and Park Commission. This would prevent duplication of activity and develop a coordinated program. It would remove the State Forester from the Conservation and Survey Division, place the forest survey and research under the Biological Survey of this Division and make the Extension Forester our State Forester.

Objectives. The objectives of an Agricultural Forestry Program should be to maintain and improve agriculture and living conditions, by:

1. Conserving the soil and improving moisture relations.
2. Protecting farm crops, gardens, etc. from critical hot winds.

3. Improving wild life habitat.
4. Producing wood products, primarily fuel, fence posts, and rough lumber.
5. Protection of people and livestock from climatic extremes and improving living conditions in general.

CONSERVATION OF WILD LIFE HABITAT

Since the days of the open prairie, natural brush lands, woodlands, streams, lakes and marshes we have made it nearly impossible for wild life to survive in Nebraska. First, we destroyed the natural living conditions of fish, birds, mammals and other forms; second, as "sportsmen," we killed most of the surviving stock; and third, we are now trying to "conserve" the remaining wild life for fishing and hunting, knowing as we must, that the way to save this life is by re-establishing the conditions (habitats) under which it can live and reproduce.

The destruction of brush land and forests; the burning and over-grazing of prairie and marsh the turning of the native sod; the draining of marshes and lakes; the straightening of streams; and the pollution of streams and lakes have destroyed the habitat relations of wild flowers and wild fruits, and the home and food relations of the native song birds, game birds, fish, fur-bearing animals and other forms and changed the migration ways of the avian fauna. Consequently, the thing to do now is to restore suitable habitats. This means, for example, that if they survive, there must be permanent waters suitable for fish; brush land for protection and feed for quail; trees and shrubs for song birds; prairie and natural feed for grouse and prairie chickens; waters and feeds for ducks, coots and shore birds; and refuge areas for the breeding and migrant wild life.

Cooperating with State and Federal departments, the Biological Survey of the Conservation and Survey Division is making close studies of the wild life habitats of the state. The results of this survey are to be used by the State Fish, Game and Parks Commission in the protection and conservation of wild life resources.

WATER CONSERVATION

The discussion under this head relates more to water than to land-water relations. It is a review of (1) water policy, (2) hydro-electric power, (3) flood control, (4) well water, (5) artesian water, (6) springs, (7) improvement of well water supplies, (8) water pollution, (9) water treatment and (10) interstate relations.

Policy. The water conservation policy of the state is based on factual surveys, conditions of occurrence, needs, vested rights and beneficial use.

According to the policy as now understood, the water resources are to be allocated and developed in ways that will result in the maximum use

and benefit to the state. This means, for example, that the waters of the Platte Valley are to be conserved for multiple use for wild life, power, irrigation, sub-irrigation, domestic and industrial purposes, i.e., by repeated diversion, storage and use in proper sequence from the headwaters in Colorado and Wyoming to the junction with the Missouri. Other phases of the policy relate to the conservation and development of groundwater, soil moisture, springs, small streams, marshes and lakes.

Hydro-Electric Power. The water powers of the state were described by the author in the 1930 Nebraska Blue Book, and, due to lack of space, only the new Federal projects are reviewed in this paper.

The total generating capacity of the 45 hydro-electric plants operated in the state in 1936 is about 16,000 KW. This does not include the Lingle and Guernsey plants in Wyoming, which have a combined capacity of 7750 KW, which were built with Federal funds assessed against irrigation lands located principally in Nebraska, and from which current is distributed generally in the North Platte Valley in Nebraska.

The projects now under construction and nearing completion in Nebraska have a combined generating capacity of about 76,700 KW or an annual production of 282,000,000 KW-hrs. of firm power. In addition, projects seeking Federal approval and the allocation of funds for development, if allowed, will have a capacity of about 54,000 KW and produce about 218,000,000 KW-hrs. of firm power annually, making the total annual output by the new and potential projects about 500,000,000 KW-hrs.

The objective now is to obtain the dual use of water, i.e., for power and irrigation where possible and feasible, and with the increased demand incident to growth in population and industry, develop power at the Tri-County, North Loup, Middle Loup and other projects, to supply the market demand. Following are summarized data on the two large power projects that are nearly completed.

Platte Valley Public Power and Irrigation District, known as the *Sutherland Project.* Its location is shown on Figure 2. Data on it are summarized as follows:

1. Diversion dam, west of Keystone, Keith county.
2. Supply canal, length 33 miles, including a big cut, and a siphon under the South Platte east of Paxton.
3. Sutherland reservoir; area 5,000 acres, capacity, 175,000 acre feet.
4. Outlet canal, length 20 miles, capacity 1400 c.f.s.
5. Regulating reservoir, area 1600 acres; capacity 19,000 acre feet.
6. Head, 206 feet.
7. Turbines, 2.
8. Power house, southeast of North Platte, generating capacity, 29,000 KW. Annual production, about 100,000,000 KW-hrs. firm power.

9. Cost of project $7,500,000 subsidized by Federal Government with repayment from sale of power and supplemental water for irrigation. This project is nearing completion. As noted before, it is to supply water for irrigation districts east of North Platte.

Loup River Public Power Project. The location of this project is shown on Figure 2. Data on it are summarized as follows:

1. Priority date, September 15, 1932.
2. Allocation, 3,500 second feet.
3. Length of canal, about 35 miles.
4. Regulating reservoir, area 1,000 acres; capacity, about 11,000 acre-feet.
5. Turbines at Columbus, three, diameters 20 feet, length 300 feet.
6. Head, 32 feet at Monroe and 112 feet at Columbus plant.
7. Power houses, two, known as the Monroe and Columbus plants, generating capacities of 7,800 KW and 39,900 KW, total about 47,700 KW; annual production probably 182,000,000 KW-hrs. of firm power.
8. Tail race or spillway, from Columbus power house to the Platte River southeast of Columbus.
9. Project, to be completed early in 1937, cost about $7,500,000 subsidized by Federal Government, self-liquidating, repayment to be made from sale of power.

Transmission Lines. The large Federal Power Projects are being tied together by high voltage trasmission lines in order to avoid standby costs and increase the dependability of service. The hookup will include Sutherland, Tri-County, Columbus and Loup projects and will serve the rural electrification districts, institutions and municipalities in southern, central and eastern Nebraska.

The cost of the power distribution system, which is subsidized by the Federal Government, will be more than $3,500,000.

Flood Control. Every large stream of the state has reached the flood state in some part of its course. However, the 1935 flood of the Republican was the outstanding one of record because of its magnitude, damage to property and the loss of human life.

Just how to regulate or control the floods of the Republican and other rivers of the state is not agreed because of the relation their regulation bears to water conservation, irrigation and other water use. For example, a setup has been made for the control of the Republican floods by means of reservoirs and river control work, but according to it the reservoirs would be emptied when the water should be held for irrigation and other purposes. Consequently, it may be advisable to compromise between flood control and the beneficial use of water.

Some hold that the cost of complete flood control on the Republican would be prohibitive and therefore not feasible and that a better way would be to adjust the land-use in the valley so that the farming and homes would be placed on the terraces and slope lands and the flood land would be used for grazing, native hay production and forestation.

To straighten the Republican without the installation of river control measures would result in the erosion and deepening of its channel to the extent that the groundwater would be drained from the bottomlands of the valley where it is the dependable source of well water. Engineers of the War Department are now making a field survey of the valley, to determine how to control the floods, and others are engaged in making a setup for irrigation. The findings of these and other groups will serve as a basis for deciding what should be done to regulate the flood hazard and the water and land-use of the valley.

Water Pollution. Our streams are being polluted by garbage dumped along them and by running industrial wastes and sewage into them. This disposal of foul materials should not be permitted because it makes the streams unsightly, filthy and unsuited for bathing, boating and wild life and because there are modern methods for sewage treatment and disposal. Pollution of our lakes is making them unsafe for bathing and too foul for wild life.

Shallow groundwaters absorb the odors and decay of organic materials becoming not safely potable. Micro fauna and flora including bacteria live in surface waters and to some extent in groundwater. The presence of nitrifying bacteria and Bacillus colon in water indicates that it may not be safe for drinking.

Water pollution is becoming a menace in Nebraska. It should be regulated and controlled. Our state should no longer permit untreated sewage to be run into the creeks and rivers.

Sanitary Well Water. Most of the state's drinking water is drawn from groundwater through wells, only a few cities being supplied from streams. Generally, except in a few small areas, there is abundant well water in the state, yet some town wells and many farm wells are not sanitary.

The Water Survey has been active the past few years in a survey of the water-bearing formations, and the source, depth, quality, and the direction and rate of movement of the groundwater. The data obtained are used in the development of sanitary rural and urban water supplies. The following statements and principles relate to well water conservation in Nebraska:

1. Open wells are not sanitary.
2. The well driller must know the structure of the land, the depth of the water table and the direction of groundwater movement in order to determine the sanitary location of a well.

3. Wells should be located where they will not catch the polluted underflow from privy vaults and other sources. This means that they should be located up-gradient (water table slope) from sources of contamination.
4. In the case of a farm home, town, or city located in a broad valley, the well or wells should be placed up-valley and the sewage disposal down-valley from the home, town, or city.
5. Every municipality should protect its water-producing ground against pollution or relocate the water supply on clean ground that can be protected.
6. Wells should be graded up and enclosed to prevent the entry of surface drainage and the trapping in them of frogs, mice, rats, and other animals.
7. In places where the groundwater is separated by clay layers as first, second and third waters, the well should be sunk to the lower water-bearing sands and the upper water, which may be polluted, should be cased off.
8. Spring water from polluted ground should not be used for drinking purposes.

Control of Artesian Water. There are more than 1,500 flowing wells in Nebraska, their depths ranging from 50 to 2,000 feet. Many of them supply good potable water whereas others yield saline or heavily mineralized water.

At places, as in the northeastern counties, the artesian water in the Dakota sandstones is the only dependable source of the rural and urban water supplies. Several wells were drilled to this water during the dry years of 1934 and 1936. Unfortunately, however, many of the wells sunk to this horizon in the Dakotas, Iowa, and Nebraska in years past have been allowed to flow unrestricted, resulting in wastage and the reduction of artesian pressure.

The wastage of this artesian water has continued too long, with unfavorable results. The Dakotas have enacted laws for the control of artesian wells and the last Legislature of Nebraska passed a joint resolution directing the State Geological Survey to take the necessary steps to protect the artesian waters of Nebraska. As a result, the Survey has been instrumental in correcting the wastage at a number of places, and it seems now that the duties of the Survey in this line should be defined by law.

Well Drillers Association. The Nebraska Well Drillers Association is one of the largest of its kind in the United States. Its members cooperate with the Geological and Water Surveys of the University in a program of water well improvement. The surveys offer annual short courses and ex-

tension service for the drillers, and they report to the surveys on well logs, the depths and types of wells and other valuable data.

Springs. Many of our springs are used for rural and some for small urban water supplies. Some of them have been improved, i.e., made more sanitary and usable with less wastage. Since the summer of 1934, Federal funds and relief labor have been used in the development of springs in areas where there is scant well water supply.

Water Treatment. Polluted waters are not safe for domestic use without treatment with chlorine, iron sulphate or other materials, and water having physical defects in color and turbidity should be corrected by sedimentation, the use of coagulants or by filtration. Finally, water softeners are used to correct the hard waters, and certain materials are used to remove excess iron or manganese. Thus far no practical method has been found for improving the potability of salt water.

Much of the well water of our state is naturally safe for drinking, and water treatment is less common than in other states. The careless disposal of sewage and industrial wastes pollutes our groundwaters, lakes and streams, making water treatment more necessary than in the past. The State Board of Health passes upon the potability of water supplies.

Navigation. Although a few row boats and small motor boats use our streams, lakes and reservoirs in season there is no navigation proper within the state. However, the Missouri River is to be made navigable as far north as Sioux City by the close of 1937. Just how beneficial this development may be for Nebraska cannot be adjudged at this time. However, Federal engineers have reported favorably on the navigation possibilities of the Missouri in its course between Sioux City and its junction with the Mississippi .

The structures being installed to control the river within a definite course will also prevent bank erosion (Figure 8) and the destruction of agricultural land along the river. The Fort Peck reservoir in Montana, is intended to regulate the river flow by storing its flood and releasing it during the low stages of the river. This, too, may prove beneficial to Nebraska.

Inter-State Relations. The Republican, Platte, Blue, Niobrara and Missouri are inter-state streams. Also, some of the groundwater, as in the artesian aquifers, moves underground independently of state lines, being recharged in one or more states and released for use in others. Consequently, the allocation, use and conservation of both the surface and groundwater have some important inter-state or national relationships which are not adequately covered by state and Federal enactments or by compacts between the states concerned. Our state should take every means necessary to protect its right to the inter-state water resources.

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References. The following list of references was prepared by W. R. Johnson of the Geological Survey:

Anderson, Arthur, Land Utilization Studies: Nebraska State Board of Agriculture Annual Report, 1935, pp. 133-147.

Baker, O. E., Three Trends to be Considered in Relation to a Land Use Program: Nebraska State Board of Agriculture Annual Report 1935, pp. 153-174.

————, The Outlook for Land Utilization: Nebraska Crop Growers' Assoc., 23d Annual Report, pp. 32-58, 1932.

Bates, C. G., and Zeasman, O. R., Soil Erosion—A Local and National Problem: Wisconsin University, Agricultural Experiment Station Research Bull. 99, 1930.

Beltner, F. D., How to Farm Irrigated Land Successfully: Nebraska State Irrigation Assoc., Proc. 38th Annual Convention, pp. 50-70, 1930.

Bengtson, N. A., Is the Rainfall of Nebraska Decreasing: Nebraska State Board of Agriculture Annual Report 1935, pp. 174-184.

Bennett, H. H., Soil Erosion: A National Menace: Journal of Forestry, vol. 26, pp. 520-527, 1928.

————, and Chapline, W. R., Soil Erosion a National Menace: U. S. Department of Agriculture Circular 33, 1928.

————, and others, Report of the Great Plains Drought Area Committee, 1936.

Bennison, E. W., The Construction of Irrigation Wells: Nebraska State Irrigation Association, Proc. 16th Annual Convention, pp. 95-108, 1926.

Brackett, E. E., Facts and Figures of Pump Irrigation: Nebraska State Irrigation Association, Proc. of 18th Annual Convention, pp. 157-170, 1928.

————, Pump Irrigation for Orchards: Nebraska State Board of Agriculture Annual Report 1935, pp. 534-536.

————, and Lewis, E. B., Pump Irrigation Investigations in Nebraska: Nebraska Experiment Station Bulletin 282, 1933.

————, Pumps and Power for Irrigation: Nebraska Irrigation Assoc., Proc. 41st Annual Convention, pp. 123-129, 1933.

Burleigh, H. P., Methods of Ground Water Investigation in the Middle Portion of the Platte Valley: Nebraska State Irrigation Assoc., Proc. 40th Annual Convention, pp. 88-89, 1932.

Canaday, R. O., Central Nebraska Power and Irrigation District: Nebraska State Irrigation Assoc., Proc. 43d Annual Convention, pp. 64-69, 1935.

Cochran, R. L., State Water Administration: Nebraska State Irrigation Assoc., Proc. 39th Annual Convention, pp. 115-125, 1931.

————, Irrigation and Drainage Problems: Nebraska State Irrigation Assoc., Proc. 38th Annual Convention, pp. 39-44, 1930.

Condra, G. E., Geology and Water Resources of the Republican River Valley and Adjacent Areas, Nebraska: U. S. Geological Survey Water-Supply Paper 216, 1907. Out of print but found in some public libraries.

————, Geology and Water Resources of a Portion of the Missouri River Valley in Northeastern Nebraska: U. S. Geological Survey Water-Supply Paper 215, 1908. Now out of print but found in some public libraries.

————, Conservation of Irrigation Resources: Nebraska State Irrigation Assoc., Proc. 18th Annual Convention, pp. 55-63, 1923.

————, Geological Control of the Depth, Volume, Quality, Quantity, and Direction of the Movement of Ground Water in the Platte Valley area of Nebraska: Nebraska State Irrigation Association, Proc. 37th Annual Convention, pp. 128-141, 1929.

————, Lincoln's Water Supply Problems: Conservation Department of the Conservation and Survey Division, University of Nebraska, Bulletin 4, 1930.

————, The Conservation of Nebraska's Water Resources: Conservation Department of the Conservation and Survey Division, University of Nebraska, Bulletin 3, 1930.

————, Conservation of the Wild Life of the Sandhill Lakes: Nebraska Blue Book, pp. 434-436, 1930. May be found in public libraries.

————, Nebraska's Natural Resources: Nebraska Blue Book 1930, pp. 404-433, 1930.

————, Water Resources Problems in Nebraska: Nebraska State Irrigation Assoc., Proc. 39th Annual Convention, pp. 91-109, 1931.

————, The Ground Water and the Lakes of the Sandhill Region of Nebraska: Nebraska Irrigation Assoc., Proc. 40th Annual Convention, pp. 42-48, 1932.

————, Nebraska's Water Resources: Nebraska Blue Book, pp. 419-430, 1932. May be found in public libraries.

————, Geography, Agriculture, Industries, of Nebraska, pp. 39-97. University Publishing Company, Lincoln, 1934. May be found in schools and public libraries.

————, Geological Phases of Soil Erosion Investigation and Control in Nebraska: Nebraska Geological Survey Paper 6, 1934.

————, The Relation of Drouth to Water-Use in Nebraska: Conservation Department of the Conservation and Survey Division, University of Nebraska, Bulletin 6, 1934.

————, The Groundwater Resources of Nebraska. About 40 pp., 1934. To be published by the National Resources Board.

————, Land-Use Problems in Nebraska: Conservation Department of the Conservation and Survey Division, University of Nebraska, Bull. 7, 1934.

————, Geologic Cross-Section, Forest City, Missouri to DuBois, Nebraska: Nebraska Geological Survey Paper 8, 1935.

————, Schramm, E. F., and Lugn, A.L., Deep Wells of Nebraska: Nebraska Geological Survey Bulletin 4, 1931.

————, and Reed, E. C., Water-Bearing Formations of Nebraska: Nebraska Geological Survey Paper 10, 1936.

Cooke, L. C., Report of the Water Planning Committee, National Resources Board: Report of National Resources Board, part 3, 1934.

Cromer, E. P., Climatic Changes Due to Irrigation: Nebraska State Irrigation Assoc., Proc. 38th Annual Convention, pp. 45-49, 1930.

Darton, N. H., Preliminary Report on the Geology and Water Resources of Nebraska West of the One Hundred and Third Meridian: U. S. Geological Survey Professional Paper 17, 1903. Now out of print but found in some public libraries.

————, Preliminary Report on the Geology and Underground Water Resources of the Central Great Plains: U. S. Geological Survey Professional Paper 32, 1905. Now out of print but found in some public libraries.

Duley, F. L., Controlling Surface Erosion of Farm Lands: Missouri University, Agricultural Experiment Station, Bulletin 211, 1924.

Follansbee, Robert, Stream Records of Nebraska: Nebraska State Irrigation Assoc., Proc. 39th Annual Convention, pp. 81-86, 1931.

Fellows, A. L., Irrigation Problems of the Great Plains: Nebraska State Irrigation Assoc., Proc. 15th Annual Convention, pp. 50-60, 1925.

Ferguson, O. J., Hydro-Electric Power: Nebraska State Irrigation Assoc., Proc. 39th Annual Convention, pp. 99-104, 1932.

Florr, Eric, Technical Features of the Loup River Public Power District Project: Nebraska State Irrigation Assoc., Proc. 43d Annual Convention, pp. 138-154, 1935.

Fulton, Robert, Hydro-Electric Power: Nebraska State Irrigation Assoc., Proc. 40th Annual Convention, pp. 99-104, 1932.

Garey, L. F., Factors Determining Type-of-Farming Areas in Nebraska: Nebraska Agricultural Experiment Station Bull. 229, 1936.

George, A. G., The Most Profitable Use of Land as Shown by Nebraska Farm Records: Nebraska State Board of Agriculture Annual Report 1935, pp. 124-132.

Good, P. F., Wyoming-Nebraska Suit: Nebraska State Irrigation Association, Proc. of 43d Annual Convention, pp. 44-56, 1935.

Gorrie, R. M., The Use and Misuse of Land: Oxford Forestry Memoirs No. 19, 1935.

Gray, L. C., and others, Report of the Land Planning Committee, National Resources Board: National Resources Board Report, part 2, 1934.

Grover, N. C., and others, Surface Water Supply of the United States, 1934, part 6, Missouri River Basin: U. S. Geological Survey Water-Supply Paper 761, 1935.

Handbook of General Information for ECW and Project Workers Soil Conservation Service Nebraska: Prepared by representatives of Soil Conservation and Nebraska Agricultural Extension Service, University of Nebraska.

Hayes, F. A., and others, See the County Soil Survey Reports of Nebraska.

Hecht, Alvah, Pump Irrigation: Nebraska State Irrigation Assoc., Proc. 37th Annual Convention, pp. 8-11, 1929.

————, Pump Irrigation: Nebraska State Irrigation Assoc., Proc. 38th Annual Convention, pp. 12-18, 1930.

————, Pump Irrigation: Nebraska State Irrigation Assoc., Proc. 39th Annual Convention, pp. 32-34, 1931.

Hoyt, W. G., and others, Studies of Relations of Rainfall and Run-off in the United States: U. S. Geological Survey Water-Supply Paper 772, 1936.

Jaquet, J. R., Republican River Flood of 1935: Nebraska State Irrigation Assoc., Proc. 43d Annual Convention, pp. 113-132, 1935.

Jarvis, C. S., and others, Floods in the United States-Magnitude and Frequency: U. S. Geological Survey Water-Supply Paper 771, 1936.

Johnson, W. D., The High Plains and Their Utilization: U. S. Geological Survey 21st Annual Report, part 4, pp. 601-741, 1901: 22d Annual Report, part 4, pp. 631-669, 1902. Out of print but may be found in some public libraries.

Kramer, E. W., and others, Handbook of Erosion Control Engineering on the National Forests: U. S. Department of Agriculture, Forest Service, Washington, 1936.

Lawrence, J. E., Making the Most of Nebraska: Nebraska State Board of Agriculture Annual Report 1935, pp. 147-153.

Lewis, E. B., Rural Electrification: Nebraska State Irrigation Assoc., Proc. 43d Annual Convention, pp. 83-98, 1935.

————, and Wood, Ivan D., Water Supply and Sewage Disposal Systems for Nebraska Farms: Nebraska Agricultural Experiment Station Bull. 245, 1930.

Lugn, A. L., The Pleistocene Geology of Nebraska: Nebraska Geological Survey Bull. 10, 1936.

————, and Wenzel, L. K., Geology and Ground-Water Resources of South-central Nebraska with Special Reference to the Part of the Platte River Valley between Gothenburg and Chapman. In press. To be published as a U. S. Geological Survey Water-Supply Paper.

McNamara, C. J., Reservoirs for the Lower Platte: Nebraska State Irrigation Assoc., Proc. 39th Annual Convention, pp 19-27, 1931.

Meinzer, O. E., Ground Water for Irrigation in Lodgepole Valley, Wyoming and Nebraska: U. S. Geological Survey Water-Supply Paper 425, pp. 37-69, 1919. May be found in some public libraries.

————, The Occurrence of Ground Water in the United States, with a Discussion of Principles: U. S. Geological Survey Water-Supply Paper 489, 1923.

————, Outline of Ground-Water Hydrology, with Definitions: U. S. Geological Survey Water-Supply Paper 494, 1923.

————, and Wenzel, L. K., Water Levels and Artesian Pressure in Observation Wells in the United States in 1935 with Statements Concerning Previous Work and Results: U. S. Geoolgical Survey Water-Supply Paper 777, 1936. Pages 86-94 refer to Nebraska.

Mickey, C. E., Water Resources of Nebraska: Nebraska State Irrigation Assoc., Proc. 37th Annual Convention, pp. 91-104, 1929.

————, and others, Special Survey Report of the Department of Public Works, Bureau of Irrigation, Water Power and Drainage, of the State of Nebraska, 1931.

Miller, M. F., Soil Management Practices to Meet Present Day Economic Conditions: Nebraska State Board of Agriculture Annual Report 1933, pp. 154-159.

Morrow, T. M., Laws Governing Interstate Streams: Nebraska State Irrigation Assoc., Proc. 40th Annual Convention, pp. 6-26, 1932.

————, Delivery of Water to Farm Units: Nebraska State Irrigation Assoc., Proc. 15th Annual Convention, pp. 60-70, 1925.

Munns, E. N., and Sims, I. H., Forests in Flood Control: Supplemental Report to the Committee on Flood Control, House of Representatives, 74th Congress, 2d Session, on H. R. 12517, 1936.

Person, H. S., and others, Little Waters. Their Use and Relations to the Land: Government Printing Office, Washington, 1936.

Porter, J. E., Storage Reservoirs from Small Streams: Nebraska State Irrigation Association, Proc. 11th Annual Convention, pp. 15-24, 1921.

Price, D. D., Platte Valley Public Power and Irrigation District: Nebraska State Irrigation Assoc., Proc. 43d Annual Convention, pp. 132-137, 1935.

Ramser, C. E., Gullies: How to Control and Reclaim Them: U. S. Department of Agriculture, Farmers Bull. 234, 1922.

————, Preventing Erosion of Farm Lands by Terracing: Agricultural Engineering, vol. 9, no. 12, pp. 369-373, 1928.

Russel, J. C., Soil Management and Crop Rotations for Northwestern Nebraska: Nebraska State Board of Agriculture Annual Report 1927, pp. 707-728.

————, Drought in Its Relation to Supplemental Irrigation: Agricultural Engineering, vol. 11, pp. 97-99, 1930.

————, Making the Most of Rainfall through Soil and Crop Management: Nebraska State Board of Agriculture Annual Report 1935, pp. 199-206.

Silcox, F. A., and others, Possibilities of Shelterbelt Planting in the Plains Region: Prepared under direction of The Lake States Forest Experiment Station, 1935.

Slichter, C. S., Description of Underflow Meter Used in Measuring the Velocity and Direction of Movement of Underground Water: U. S. Geological Survey Water-Supply Paper 110, pp. 17-31, 1904. Out of print, but may be found in some public libraries.

————, and Wolff, H. C., The Underflow of the South Platte Valley: U. S. Geological Survey Water-Supply Paper 184, 1906. Out of print but may be found in some public libraries.

Soil Conservation. Published monthly by the Soil Conservation Service, U. S. Department of Agriculture.

Stewart, P. H., and Wood, Ivan D., Soil Washing, the Cause and Methods of Prevention: Nebraska University, Agricultural College Extension Service, Extension Circular 123, 1924.

————, and Gross, D. L., The Management of Nebraska Soils: University of Nebraska, College of Agriculture, Extension Circular 134, 1932.

————, Getting the Most From Rainfall: Nebraska State Board of Agriculture Annual Report 1933, pp. 724-737.

Swenson, C. H., Conservation of Water of the Republican and Frenchman Rivers: Nebraska State Irrigation Assoc., Proc. 38th Annual Convention, pp. 72-76, 1930.

Waite, H. A., Ground Water Level Survey in Nebraska: Nebraska State Irrigation Assoc., Proc. 42d Annual Convention, pp. 80-93, 1934.

————, Groundwater Level Survey in Nebraska: Nebraska Geological Survey Paper 7, 1935.

Weakly, H. E., Pump Irrigation: Nebraska State Irrigation Assoc., Proc. 16th Annual Convention, pp. 193-198, 1926.

————, Pump Irrigation and Water Table Studies: Nebraska Agricultural Experiment Station Bull. 272, 1932.

————, Pump Irrigation at the North Platte Experimental Substation: Nebraska Agricultural Experiment Station Bull. 301, 1936.

Weiss, Andrew, Disposal of Drainage Yields, North Platte and Platte Valleys: Nebraska State Irrigation Assoc., Proc. 11th Annual Convention, pp. 40-51, 1921.

Wenzel, L. K., The Thiem Method for Determining Permeability of Water-Bearing Materials and its Application to the Determination of Specific Yield. Results of Investigations in the Platte River Valley, Nebraska: U. S. Geological Survey Water-Supply Paper 679-A, 1936.

Weaver, J. E., and Harmon, G. W., Quantity of Living Plant Materials in Prairie Soils in Relation to Run-off and Soil Erosion: Conservation and Survey Division, University of Nebraska, Bull. 8, 1935.

————, and Noll, W. C., Comparison of Runoff and Erosion in Prairie, Pasture, and Cultivated Land: Conservation Department of the Conservation and Survey Division, University of Nebraska, Bull. 11, 1935.

Whitehead, J. T., General Water Power: Nebraska State Irrigation Assoc., Proc. 37th Annual Convention, pp. 67-80, 1929.

————, Water Power: Nebraska State Irrigation Assoc., Proc. 38th Annual Convention, pp. 147-158, 1930.

————, How Shall the Waters of an Interstate Stream be Administered: Nebraska State Irrigation Assoc., Proc. 40th Annual Convention, pp. 49-55, 1932.

Wiggans, C. C., The Effects of Orchards on Subsoil Moisture: Nebraska State Board of Agriculture Annual Report 1935, pp. 516-526.

Willis, R. H., Orderly Distribution of Available Water Supply: Nebraska State Irrigation Assoc., Proc. 37th Annual Convention, pp. 41-63, 1929.

————, Bureau of Irrigation, Water Power and Drainage, Biennial Report 1933-34: Nebraska Department of Roads and Irrigation 20th Biennial Report, part 2, pp. 917-787, 1934.

Wood, Ivan D., Inexpensive Methods of Gully Control: Nebraska University, College of Agriculture Extension Service, Extension Circular 741, 1933.

————, Practical Methods of Moisture Conservation on Orchard Lands: Nebraska State Board of Agriculture Annual Report 1935, pp. 527-534.

————, Value of Terracing, Contour Farming, Strip Farming and Other Practices in Conserving Precipitation: Nebraska State Board of Agriculture Annual Report 1935, pp. 190-199.

Young, J. M., Flood Control: Nebraska State Irrigation Assoc., Proc. 38th Annual Convention, pp. 129-142, 1930.

Zook, L. L., Irrigation vs. Dry Land Farming: Nebraska State Irrigation Assoc., Proc. 18th Annual Convention, pp. 93-104, 1928.

————, Dry Land Crop Production at the North Platte Experimental Substation: Nebraska Agricultural Experiment Station, Bull. 279, 1933.

NOTE: The State Planning Board will soon publish a number of reports on the water and soil resources of Nebraska.